General Services Administration
Public Buildings Service

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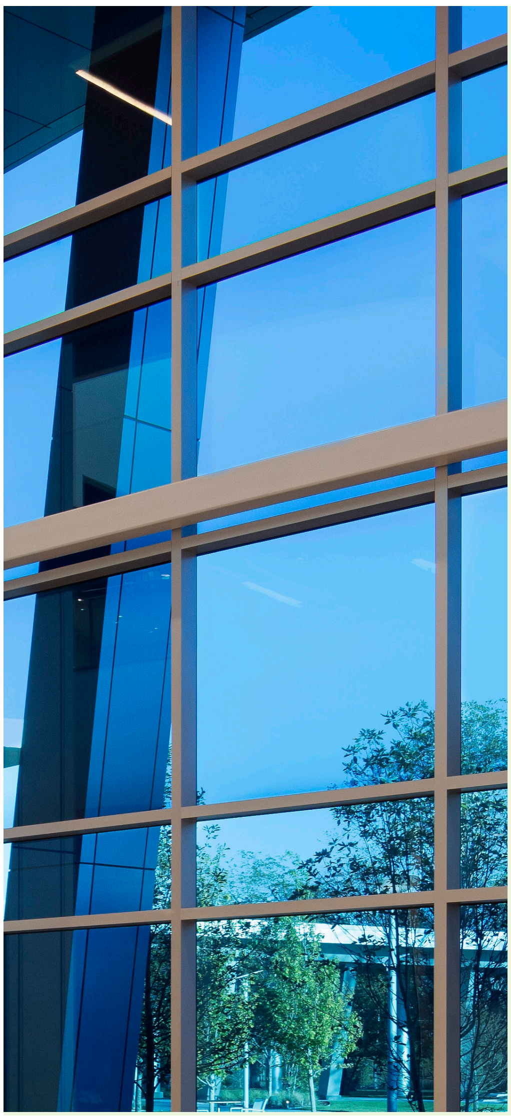
ELECTROCHROMIC WINDOWS FOR OFFICE SPACE



Occupants Prefer EC Over Legacy Windows

Electrochromic (EC) windows are part of a new class of technologies that together comprise "dynamic façades." Able to respond to their environment by changing behavior, dynamic façades are among the most significant recent developments in commercial building technology, and EC windows, with their ability to manage heat and glare actively, promise to play an important role in their evolution. To assess tenant acceptance of EC windows in buildings with glass curtain-wall façades, the Lawrence Berkeley National Laboratory (LBNL) evaluated two different test-bed installations of EC technology—one in Portland, Oregon, the other in Sacramento, California. Findings demonstrated that the majority of occupants preferred EC windows over the existing windows. On a more granular level, however, satisfaction was mixed, and it was challenging for the technology to satisfy occupants' aesthetic and glare requirements, while implementing control strategies that deliver HVAC and lighting savings. In both test bed locations, this conflict had the effect of reducing return on investment and, in the end, this evaluation concluded that broad deployment of EC windows across GSA office space would not be cost-effective based on energy savings alone. There are, however, circumstances under which EC windows would be beneficial. For instance, an earlier Center for Emerging Building Technologies (CEBT) study found that EC windows are an effective solution for facilities where window glare compromises mission-critical outdoor visibility, such as Land Ports of Entry.[1] When compared with upgrades to an HVAC system, EC windows can provide a cost-effective way to reduce peak cooling load. In addition, to help meet challenges with seasonal thermal comfort, EC windows can be used to reduce solar heat gain during summer months. Finally, architectural features, such as skylights and atriums, that connect occupants with the outdoors might benefit from the application of this technology, though this has not been evaluated.

INTRODUCTION

> "*We are considering EC windows for a federal building in Alaska where, in summer, the sun exposure on the south wall can be overwhelming, but in winter it's desirable.*"

—Marty Novini
Energy Program Manager
Northwest/Arctic Region
General Services Administration

VISIBLE TRANSMITTANCE (TVIS)
Measurements

SACRAMENTO

ORIGINAL WINDOWS
as estimated by LBNL

Tvis	**0.61**

EC WINDOWS
as specified by GSA

Tvis - 1. Clear*	**0.60**
Tvis - 2. Light Tint	**0.18**
Tvis - 3. Medium Tint	**0.06**
Tvis - 4. Full Tint	**0.01**

PORTLAND

ORIGINAL WINDOWS
as estimated by LBNL

Tvis	**0.15**

EC WINDOWS
as specified by GSA

Tvis - 1. Clear*	**0.36**
Tvis - 2. Light Tint	**0.25**
Tvis - 3. Medium Tint	**0.13**
Tvis - 4. Full Tint	**0.02**

* A blue tinted layer of glass was added in Portland to match windows in the existing façade.

What Is This Technology?

EC WINDOWS ADAPT AUTOMATICALLY TO CHANGING CONDITIONS

EC windows adjust their tint—and, thereby, the amount of light, glare and heat they allow into a room—dynamically. Combining ordinary double-pane glazing with a thin multi-layer conductive coating, EC windows transition reversibly from clear to dark blue in response to a small amount of direct current, which is transmitted either manually, by a wall switch or mobile application, or automatically, from a window control system with access to illumination sensors. The EC coating transitions, or "switches," in the visible and near-infrared portions of the solar spectrum, absorbing solar radiation and then relying on the low-emittance (low-e) properties of the coating to keep the solar heat from augmenting interior temperatures. Switching also influences the amount of daylight within the building. The number of tints and their gradations, along with other characteristics of the glass, are determined during design and specification.

What We Did

TWO EC WINDOW INSTALLATIONS IN TWO DIFFERENT ENVIRONMENTS

Previous CEBT studies validated the ability of EC technology to deliver HVAC and lighting savings as well as glare reduction. This study, conducted by LBNL, focused on occupant acceptance within general office space in two locations—one at the 911 Federal Building in Portland, Oregon, the other at the Moss Federal Building in Sacramento, California. Both facilities are curtain wall designs with large window-to-wall ratios. In Portland, EC windows were installed on the sixth and seventh floors, in a suite of private offices adjacent to the south façade. After favorable occupant feedback, the installation was expanded to include open offices adjacent to the south façade on the third, fourth and fifth floors. In its pre-retrofit state, Portland's 911 Federal Building had dark-tinted, dual-pane, low-e windows, fitted with indoor venetian blinds. The EC windows were designed to match the aesthetics of the existing window façade and, therefore, included a dark tinted glass layer. Measurement and verification (M&V) was conducted over two consecutive, six-month, solstice-to-solstice periods.

Meanwhile, in Sacramento, EC windows were installed in the south façade of the Moss Federal Building's 6th floor, replacing 84 double-pane low-e units installed in 2006. The existing windows had a high visible transmittance (Tvis) of 0.61, which was nearly identical to the Tvis of the lightest EC window tint state of 0.60 and therefore limited the potential for the EC windows to admit more daylight than their legacy counterparts. The EC windows were configured with three sub-zones that tinted independently of one another. M&V in Sacramento took place between the winter solstice of 2015 and the summer solstice of 2016.

FINDINGS

HVAC ENERGY SAVINGS MAY BE CHALLENGING TO REALIZE Previous studies and laboratory measurements of EC windows have shown that it's possible to reduce cooling loads between 10 and 20% and peak electricity demand by up to 30% in south-, east- and west-facing perimeter zones.[2] As a complement to the field studies, LBNL evaluated EC windows installed at the Advanced Windows Testbed in Berkeley, California and found reductions in daily HVAC load between 29-65% or 0.43-3.48 Wh/ft^2/day and peak load reductions between 25-58%. The test-bed evaluations demonstrated that such savings may be difficult to realize while maintaining occupant satisfaction because the darkest tint levels, which are necessary for HVAC cooling savings and glare control, are not always acceptable to occupants. For example, at the Portland test bed, the darkest automatic tint levels were disabled because occupants found them to be *too* dark, a change that resulted in an HVAC cooling load that was 2% higher than baseline conditions. When the darkest tint level (Tint 4) was tested over the weekend, when occupants were not present, researchers calculated a 57% reduction in cooling load.

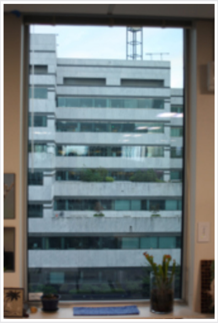
BLIND USE AND WINDOW TINT INFLUENCE LIGHTING ENERGY SAVINGS Previous EC window studies have demonstrated lighting energy savings of greater than 20%. However, to realize lighting energy savings, occupants must reduce blind use and EC window tint must be set to the lighter levels. This study was inconclusive as to whether these savings will be achieved in general office space. At the Portland test bed, where the legacy windows had a visible transmittance of 15%, lighter tint levels predominated with the EC windows and 40% more blinds were left in the fully raised position, resulting in 36% lighting energy savings. At the Sacramento test bed, windows spent the majority of the time at full tint (before the control algorithms were modified) and 67% of blinds remained more than halfway lowered, resulting in a 62% increase in lighting energy use. Researchers note that the increase in lighting energy was due to specific issues at the demonstration site and is not representative of the capabilities of the technology.

OCCUPANTS MORE SATISFIED WITH EC WINDOWS In Portland, 85% of occupants in private offices and 92% in open offices preferred EC windows over the existing windows. In Sacramento, 63% of occupants also preferred EC windows over the existing windows. Some of the issues occupants reported with EC windows, such as the time the glass took to achieve full tint, may have impacted occupant satisfaction. EC window manufacturers report faster tinting transitions in newer versions of the technology and the ability to change/abort transitions without waiting for the current transition to complete. Improved tint algorithms make better use of intermediate tint states so windows tint faster and maintain better control during partly cloudy conditions.

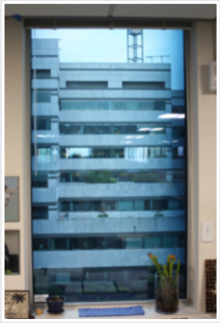
CONTROL ALGORITHMS NEED FINE TUNING While the EC window technologies operated as intended and were generally acceptable to occupants, the automatic controls were not yet turnkey. At both test beds, substantial post-installation commissioning was required to balance the competing needs of glare control, lighting- and cooling-energy savings, and tenant acceptance. In Sacramento, a single pane of glass contained multiple tint zones. At first, this was particularly challenging to control in a way that satisfied the competing performance objectives. Ultimately, however, the controls were tuned to meet the demands of the application.

LIMITED COST-EFFECTIVENESS IN GENERAL OFFICE APPLICATIONS At the GSA national average utility rate of \$0.11/kWh and a mature market cost of \$61/ft^2 (as estimated by the manufacturer) and with the continued need for blinds and their associated costs, payback at the Portland test bed was estimated at 29 years. The incremental difference between installing EC windows and spectrally selective low-e windows was estimated at \$37/ft^2 with a payback of 13 years. This cost-analysis does not include other non-energy benefits, such as a boost in health and productivity due to increased daylight and access to outdoor views.

LESSONS LEARNED



Tint 1 - 6:25 pm



Tint 2 - 6:31 pm

Tint 3 - 6:43 pm

Tint 4 - 6:53 pm

Switching Speed

Switching speed is influenced by window size and temperature. In Portland, on April 10, 2016, windows took 28 minutes to tint fully.

← Tint 4

← Tint 1

Multiple Tint Zones

In Sacramento, EC windows had multiple zones within a single glazing unit, to allow for more control of glare and daylight. In glare mode, the top and middle sub-panes are at full tint, the bottom pane is in daylight mode.

- **Select clear windows to facilitate a broad switching range** A blue-tinted layer of glass was added to EC windows in Portland to match legacy windows aesthetically in the existing façade. This limited the ability of the EC windows to admit daylight. If possible, select EC windows with a clear inboard glass layer.
- **Configure EC window installations into zones** If your installation occurs along a single orientation (a south-facing façade, for instance), consider using zones to mitigate the gloominess that might result at darker tint levels. Either add a clerestory-like daylight zone of insulating glass units above the EC window installation or control individual windows independently.
- **Review architectural drawings and other pertinent documents** Knowing in advance about the architecture of a façade or the accessibility and design of an electrical system can facilitate EC window installation.
- **Test before you install** Consider testing each EC window prior to installation. Check for manufacturing defects in the EC coating and electrical problems.
- **Educate occupants, manage expectations** Provide information on how EC windows operate and inform occupants that they can change and even override automated controls. Occupants might be more inclined to accept the way windows function (e.g. number of tints, tint levels, and length of transition between tint levels) if they understand the rationale behind the functionality. Also, consider convenient placement of wall control switches during the planning phase.
- **Proper commissioning takes time** When programming EC window control algorithms, it can be difficult to achieve an optimal balance between competing performance requirements. This is especially true for balancing glare control and lighting energy. Leave adequate time to explore options.

CONCLUSIONS

These Findings are based on the report, "Electrochromic Window Demonstrations," which is available from the GSA website, www.gsa.gov/cebt

For more information, contact GSA's Center for Emerging Building Technologies cebt@gsa.gov

What We Concluded

AT PRESENT, EC WINDOWS HAVE LIMITED GSA DEPLOYMENT POTENTIAL FOR GENERAL OFFICE SPACE

EC hardware itself is generally mature. It is able to control glare and thermal discomfort and reduce lighting energy use and HVAC cooling loads. However, these test-bed evaluations found that it was challenging to satisfy occupants' aesthetic and glare requirements, while implementing control strategies that delivered HVAC and lighting savings. For this reason, and because of its limited cost-effectiveness, widespread GSA adoption of EC windows in occupied general office space is not recommended at present. There are circumstances, however, discussed below, where EC windows could be an effective solution and should be considered:

Facilities where outside views are critical A previous CEBT study at the Land Port of Entry (LPOE) in Donna, Texas found that EC windows are a good solution for locations where window glare compromises mission-critical outdoor visibility. The EC windows at the Donna LPOE had a 100% user preference over the legacy conventional windows.

Facilities with seasonal thermal comfort challenges EC windows can be an effective solution for buildings whose occupants experience seasonal thermal discomfort and where it is beneficial to have dark tinted glass in the summer, but clear glass in the winter.

Facilities with atriums and skylights While atriums and skylights can provide valuable connection with the outdoors, they also can result in significant solar heat gain and consequent occupant discomfort. The evaluation team believes that EC glass can be an effective solution for this application, though it has not been evaluated.

Public spaces in new construction Public spaces, such as lobbies and conference rooms, where views are important, but blinds unnecessary or impractical, present an opportunity for EC windows.

Facilities needing to reduce peak cooling load When compared with upgrades to an HVAC system, EC windows can provide a cost-effective way to reduce peak cooling load. As seen in Portland, however, the ability to reduce HVAC load is dependent, during occupied periods, on occupants accepting darker tint levels.

Facilities with radiant cooling Buildings with low-energy cooling systems, such as radiant cooling, are likely to benefit from the dynamic control provided by EC windows because such HVAC systems take longer to respond to atmospheric conditions.

Footnotes

[1] Electrochromic Window Demonstration at the Donna Land Port of Entry. Eleanor S. Lee (LBNL), May 2015 (https://www.gsa.gov/cebt)

[2] A Pilot Demonstration of Electrochromic and Thermochromic Windows in the Denver Federal Center, Building 41, Denver, Colorado. Eleanor S. Lee (LBNL), March 2014 (https://www.gsa.gov/cebt)

Technology for test-bed measurement and verification provided by View Dynamic Glass and SageGlass.